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Estimating the greenhouse gas footprint of Knorr

Llorenç Milà i Canals · Sarah Sim · Tirma García-Suárez · Gabriele Neuer · Kathrin Herstein · Colin Kerr · Giles Rigarlsford · Henry King

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Abstract
Purpose Greenhouse gas (GHG) emissions have been identified as one of Unilever's priority environmental impact themes: this assessment was therefore conducted to help the Knorr brand measure and understand the GHG emissions related to its product portfolio, identify opportunities to manage GHG emissions in the Unilever-owned operations (manufacture) and influence managed reductions elsewhere in the Knorr product lifecycles, and assess the impact of the brand's innovation and portfolio strategies on its GHG footprint.
Methods A bottom–up product-based life cycle assessment (LCA) approach was considered impractical to assess Knorr's portfolio's complexity. Thus, a meta-product-based accounting LCA approach was followed (Milà i Canals et al. 2009). Up to 16 product types or "meta-products" were assessed in each geographical region, with a total of 36 meta-products assessed globally. Then, the Knorr GHG footprint was derived by multiplying the impacts calculated per tonne of each product type with the sales volumes in 2007. Data for ingredients and processing technologies were gathered from the literature and suppliers; data from Knorr factories were used for the manufacturing stage. The variability in ingredients' production and processing and in manufacture was factored in and propagated through the calculations to assess the robustness of the results.
Results The profiles of different meta-products within a product group (e.g. dry soups) follow similar patterns in terms of absolute GHG per tonne and distribution of such emissions along the life cycle. Variations are observed due to recipe composition and electricity mixes in the different regions. The range of variability around absolute results is significant and varies between meta-products. Aggregating the results for individual meta-products with their production volumes, the global Knorr brand GHG footprint in 2007 was estimated to be in the region of 3–5 million tonnes CO_2e/annum (95% confidence interval). In spite of the significant variability ranges found, the results are useful for target setting and identification of opportunities for improvement.
Conclusions This is the world's first life cycle GHG assessment at brand's product portfolio level. The meta-product approach simultaneously allows for the assessment and comparison of individual product types as well as for the estimation of a brand's total GHG. The variability assessment enhanced robustness of the results by identifying a confidence range; given the complexity of the studied supply chains and the current data quality translated in wide confidence ranges, single number on-pack carbon labels seem questionable and not robust enough to inform consumers.

Keywords Bouillons · Greenhouse gas (GHG) footprint · Knorr · Meta-product · Soups

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L. Milà i Canals (✉) · S. Sim · T. García-Suárez · G. Rigarlsford · H. King
SEAC, Unilever R&D,
Colworth Park,
Sharnbrook, Bedfordshire MK44 1LQ, UK
e-mail: Llorenc.Mila-i-Canals@Unilever.com

G. Neuer · K. Herstein
Product Development Savoury, Unilever R&D Heilbronn,
Knorrstr. 1,
74074 Heilbronn, Germany

C. Kerr
Category Packaging, Unilever R&D Port Sunlight,
Quarry Rd East,
Bebington, Wirral CH63 3JW, UK

1 Introduction

Knorr is one of the world's largest food brands, and the largest Unilever brand, with a presence in approximately 90 countries. Its product portfolio includes dry and wet soups, bouillons and sauces, fruit and vegetable shot drinks (100-ml mono-doses of fruit and vegetable concentrates designed to boost daily intake of fruit and vegetables) as well as frozen meals and 'meal-makers' (i.e. seasoning mixes for specific dishes, e.g. stir fries, stews, casseroles, etc.). Knorr product supply chains are truly global with many thousands of ingredients sourced from around the world. This paper describes an approach to calculate the annualised greenhouse gas (GHG) footprint (GHGF[1]) of the total product portfolio of the Knorr brand and its main product types. The issue of GHG emissions has been identified as one of Unilever's priority environmental impact themes alongside water, waste and sustainable sourcing: this assessment was therefore conducted to help the Knorr brand:

1. measure and understand the GHG emissions related to its product portfolio;
2. identify opportunities to manage GHG emissions in the Unilever-owned operations (manufacture) and influence managed reductions elsewhere in the Knorr product lifecycles; and
3. assess the impact of the brand's innovation and portfolio strategies on its GHG footprint.

The goal was not to align to any specific initiative aiming to standardise GHGF methodology (see e.g. Finkbeiner 2009); a basic life cycle assessment (LCA) approach was used and adapted for the purpose of the study. Unilever routinely measures and reduces in-house GHG emissions from energy per tonne of production (with a 41% reduction of GHG emissions in manufacture between 1995 and 2009, Unilever 2010); however, this is estimated to represent only 1–2% of the overall emissions caused by Unilever products along their life cycle (Unilever 2010). Thus, the main opportunities for improvement lie upstream/downstream from the factories. We need to measure and understand such impacts in order to manage them, and to ensure focus on the key areas to enable reductions to be made, which requires a product (life cycle) perspective. Unilever is investing significantly in this type of activity as part of a new vision to double the size of the business while reducing its overall environmental impact across the entire value chain (Unilever 2010).

Section 2 presents the meta-product approach developed to allow the assessment of Knorr's complex product portfolio (2.1); how it was applied to derive a GHG footprint for individual product groups and the whole brand (Section 2.2); and finally, the variability assessment undertaken to ensure the robustness of results (2.3). Section 3 presents the results, first at a meta-product level and then at the brand level, highlighting the main opportunities for improvement. Section 4 provides some discussion of the results in the light of other simplified life cycle approaches, and Section 5 concludes with the implications for Knorr's innovation strategy.

2 Materials and methods

2.1 Meta-product approach

Knorr's product portfolio includes over 7,500 different 'stock-keeping units' (SKU: product/packs reflecting individual recipes, pack sizes and formats); this complexity made a bottom–up, conventional product-based GHG footprint approach impractical. A "meta-product" approach was thus developed whereby "product types" which are representative[2] of the Knorr portfolio (e.g. dry soup–instant; dry soup–cook-up; wet soup–can; wet soup–aseptic…) were adopted (Milà i Canals et al. 2009). Meta-product is used here to refer to an abstraction of a product group that describes that product group; e.g. we define a meta-product called "dry soup–instant" with an average recipe that does not exist in the market, but is a good-enough representation of the hundreds of variants of instant dry soups in the market. The meta-product concept has been used before in product eco-design guides, where it is suggested to avoid the "paralysis by analysis": we do not need to perform yet another LCA of a specific washing machine model before we can say what needs improving in the design, as the answer is 95% known, thanks to studies of previous machines. In other words, the meta-product "washing machine" has a consistent GHG profile, and specific products only modify this slightly. The production impact for each meta-product was derived from the dominant production technology, typical packaging materials and average recipe composition (derived as a weighted average of the 10 topseller SKU recipes for each product type). Meta-products were defined for each region in which Knorr products are marketed (e.g. Europe, North America, Latin America…). Up to 16 product types or "meta-products" were assessed in each geographical region,

[1] Carbon Footprint, "the total set of GHG emissions caused directly and indirectly by an individual, organisation, event or product" (The Carbon Trust 2007), is a more common denomination. However, in this study we prefer using GHGF as a synonym of carbon footprint, as we consider GHGF is a more adequate term

[2] Representative product types were selected as those with the highest sales volumes. Part of the total Knorr production volume has not been specifically studied, but extrapolated from these main product groups.

with a total of 36 meta-products assessed globally. This allowed for regional differences in the product portfolio to be reflected in the assessment, as well as differences in impacts due to variations in energy provision, technology, distances and modes of transport, etc. The total, global Knorr GHG Footprint was derived by multiplying the GHG impact calculated per tonne of each meta-product with the regional sales volumes in 2007.

The simplified meta-product approach to data collection and GHG calculations is summarised in Fig. 1, and was complemented by a variability analysis in the ingredients' production and processing as well as the manufacturing stages. In relation to some of the key challenges identified by Finkbeiner (2009) for GHGF standardisation, the following considerations were made: economic allocation was used in most circumstances because (as usual in agricultural systems) many of the ingredients' production systems co-produced large volumes of low-value by-products; most data used were of secondary origin due to the challenge of collecting primary data for thousands of different ingredients and processes, and thus some methodological choices were beyond our control (e.g. allocation methods); emissions from land use change (LUC) were not included for most processes, with the exception of those in which literature studies include LUC (e.g. in ecoinvent datasets of soya bean and palm oil); indirect LUC was not considered at all; carbon storage was not considered due to the short life of the products being studied.

2.1.1 Meta-products description

The following meta-products were assessed in the study and are presented in this paper (further meta-products are not shown here for the sake of simplicity; these include granulated bouillons and fruit and vegetable shots). They were defined by a specific technology and/or a preparation mode. In addition, some were further differentiated by packaging format (which is often related to the manufacturing technology):

- *Wet soups*: these soups are ready-to-use and only require heating (in a sauce pan on a hob or in a suitable dish in the microwave) before consumption; they are packed in laminated cardboard, flexible stand-up pouches or tins. Depending on the packaging, three main manufacturing technologies are distinguished:
  - Wet, aseptic: ingredients are weighed and mixed, sterilised, cooled, filled aseptically in pre-sterilised (H_2O_2) cardboard containers
  - Wet, doy packs (flexible pouches): ingredients are weighed, mixed, heated (with holding time), filled in pre-sterilised, retortable pouches, pasteurised and cooled down
  - Wet, cans: ingredients are weighed, mixed, filled in cans, sterilised and cooled down
- *Dehydrated (dry) soups* in pouches are defined by the manufacturing technology, which involves: weighing and mixing of dehydrated/dry ingredients, filling into pouches, and packing. Depending on the use, two main types are distinguished:
  - Dry soups, cook-up: the "soup powder" is stirred into cold or boiling water and cooked for a certain time (1 to 10 min); cook-up soups usually contain 2–4 servings and are sold in flexible pouches (with or without aluminium)
  - Dry soups, instant: boiling water is poured over the "soup powder" and allowed to stand for some minutes (3–5); instant soups contain 1 serving; they are packed in flexible pouches, often several pouches are sold in a cardboard box

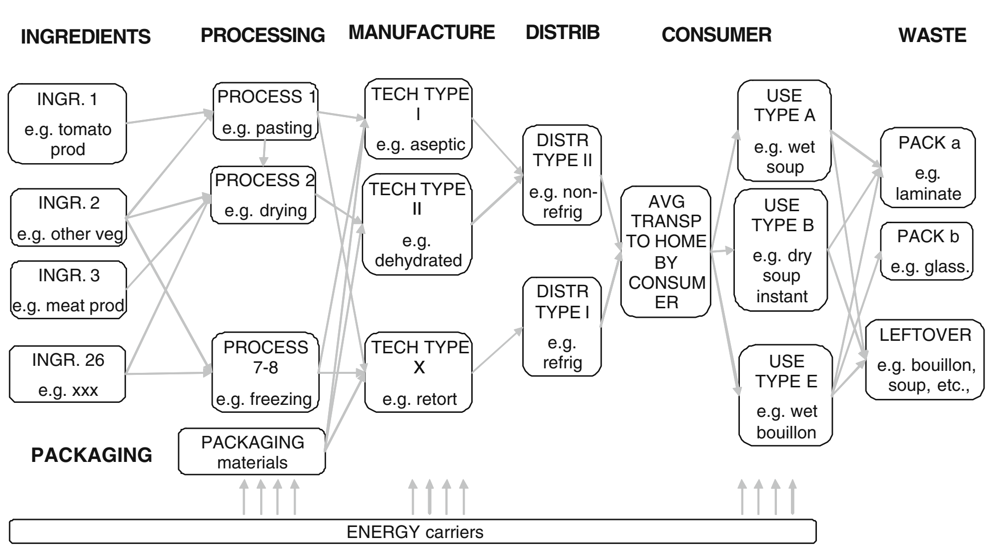

Fig. 1 Simplified process flow diagram illustrating the building blocks developed for the assessment of Knorr meta-products

- *Bouillon cubes*: to prepare a bouillon, bouillon cubes are added to boiling water and cooked until dissolved; the cubes are individually wrapped in aluminium foil and packed in a cardboard box. Two main manufacturing technologies are distinguished:
  - Pasty bouillon: hot fat is left to pre-crystallise, then ingredients and fat are mixed, followed by maturation, mechanical and granular shearing and extrusion; the cubes are subsequently wrapped and packed
  - Pressed (dry) bouillon: ingredients are mixed, followed by maturation, graining and pressing of cubes; the cubes are subsequently wrapped and packed
- *Bouillon jellies*: this is a novel technology, in which ingredients are mixed, heated, pasteurised, flushed with nitrogen, filled into tubs, sealed and packed. To prepare a bouillon, a bouillon jelly is added to boiling water and cooked until dissolved; the jellies are packed in plastic tubs with a cardboard sleeve or box
- *Liquid bouillons*: ingredients are mixed into warm water, heated to 95°C, cooled to 20–25°C, and filled into packaging. For preparation:
  - Ready-to-use (RTU) liquid bouillons only require heating (in a sauce pan on a hob or in a suitable dish in the microwave) before consumption; they are packed in doy packs (flexible stand-up pouches) or aseptic laminated cardboard
  - On the other hand, a small quantity of a concentrated liquid bouillon is added to boiling water to obtain a bouillon or—as a seasoning—only a few drops are given to various dishes; these concentrated bouillons are packed in glass or PET bottles

2.2 Life cycle stages modelling

Instead of assessing the GHG emissions of each of the thousands of ingredient specifications, ingredients and processes considered as similar were aggregated in 'building blocks' (e.g. 'dairy products' instead of milk, cream, etc.; 'drying' instead of air drying, spray drying, drum drying, etc.). This approach is similar to studies dealing with large numbers of input ingredients, such as diet assessments (see e.g. Foster et al. 2006; Muñoz et al. 2010; Wiltshire et al. 2010). Most cradle-to-gate (or gate-to-gate, for processing) data on ingredients' production and processing were sourced from the literature (167 datasets used in total), although primary data for some (e.g. flavours, taste enhancers, juicing and concentration…) were sourced directly from suppliers. Representative transport distances for ingredients were modelled depending on the main sourcing regions and were in the order of 2,000–7,000 km by ship (+1,000 km by truck) for those long-lived ingredients that can be sourced globally (e.g. fruit, animal products, starches…) and approximately 1,000 km by truck for ingredients which tend to be sourced regionally (e.g. eggs, dairy, fresh vegetables…). Packaging material production was modelled with ecoinvent data complemented with supplier data on certain processing steps (e.g. lamination). Data on the manufacture of the final products were obtained directly from Unilever production sites for each of the technologies involved (Table 1). Product use at home was modelled according to the instructions on the product label; the general formula suggested by Sonesson et al. (2003) for boiling on a hob was used, setting the boiling time to zero when soups are only heated up. It must be highlighted that bouillons are often not used as such (i.e. drunk as a "clear soup") but as seasoning in various dishes (e.g. in a stew or a rice dish); in these cases, it could be argued that the impact of preparing the bouillon should be allocated to the dish, and not to the bouillon. Thus, the impacts ascribed to the bouillon in the use phase represent the "worst case" of all impacts being ascribed to the bouillon.

2.3 Variability analysis

To assess the robustness of the results, the variability associated to the GHG emissions of ingredients, processing,

Table 1 Estimated utility consumption (weighted mean; σ_g^2 (geometric standard deviation)) for the production technologies assessed in European sites

Technology type	*n*	Electricity kWh/T		Steam purchased kg/T		Natural gas m^3/T	
		Mean	σ_g^2	Mean	σ_g^2	Mean	σ_g^2
Dehydrated in pouches	8	183.3	1.7	0		4.9	5.1
Aseptic	2	202.6	1.7	0		43.7	1.2
Retorted	3	46.7	11.7	0		14.4	16.0
Hot filled and hold	1	200.0	1.2	548.0	1.2	66.8	1.2
Tunnel pasteurise	3	42.5	2.3	0		20.1	2.2
Pasty bouillon	3	261.0	1.1	0		13.7	6.1
Dry bouillon	2	299.4	3.4	731.4	1.2	0	
Granule bouillon	2	264.9	1.4	0		16.3	47.1

n number of sites for which data were available on a specific technology

and manufacture building blocks was individually assessed and propagated through the calculations. Variability in distribution (distances and modes) and particularly consumer use (appliances and cooking habits) may be large, but were not included in the assessment due to lack of data in the case of the use phase, and ease of modelling scenarios with different distances in the case of distribution. On the other hand, it was key to assess the effect on the final results of grouping many inherently variable ingredients in the same building blocks, as it is acknowledged that variability is further increased by the grouping exercise. Such variability in environmental impacts is accentuated in the case of food ingredients and other bio-based products due to differing sources, seasons, cropping techniques, etc., but this is an issue for any environmental impact assessment theme, not just the GHG footprint. In any form of impact assessment, the variability and uncertainty around the results should always be considered in the interpretation to judge whether the results are appropriate for the intended goals.

For most ingredients, only data at the impact assessment level (kilogram CO_2e per kilogram ingredient) were available, and therefore, these were used to estimate and propagate variability. Consequently, variability of individual datasets and uncertainty introduced by life cycle impact assessment (LCIA) models were unavoidably mixed to some degree. This is not ideal, but many studies in the literature do not provide the life cycle inventory (LCI) results, and it was felt that including the variability somehow was more important than ignoring this altogether or focus on the few studies that offer LCI information (which would have forced a much reduced number of less representative building blocks). For most processing technologies and manufacture (and some ingredients), variability was assessed at the level of inventory inputs (energy use).

In this work, a lognormal distribution was fitted to the values found whenever two or more datasets were available; when only one dataset was available, the Data Quality Indicator (DQI, Weidema and Wesnæs 1996) approach was used to evaluate a measure of variability from the uncertainty in the datasets, in a similar way as suggested in ecoinvent (Frischknecht et al. 2008). Apart from the five conventional uncertainty factors (geography, time, technology correlation…) ecoinvent introduces a sixth factor to express "natural" variability (U_b). By back-calculating the values of U_b needed to explain variability in cases with enough datasets, it was found that the factors applied in ecoinvent tend to underestimate the measure of variability for many of the activities, particularly those relating to agriculture, at least when used with LCIA results. Table SI 1 in the Supporting Information shows the GHG emission values considered (geometric mean as well as the upper and lower bounds calculated through the variability assessment) for most of the ingredients sourced from the literature.

The propagation of variability through the LCA calculations was assessed with 10,000 runs of Monte Carlo simulations in GaBi 4 Analyst Tool for each meta-product. Due to the fact that GaBi Analyst does not yet work with lognormal distributions, skewed normal distributions were modelled by adding different values to the lower (−SD) and upper (+SD) bounds of the Monte Carlo assessment. The distributions were not truncated with minimum and maximum values.

2.4 Impact assessment

The GHGF was calculated with the latest global warming potential (GWP) values provided by the Inter-governmental Panel on Climate Change as reported in the CML 2007 GWP method. The method was slightly modified in order to ignore the fixation and emissions of biogenic C i.e., fixation of atmospheric CO_2 by plants was neglected, as well as the emissions of digestion and incineration of biomass into CO_2; a GWP of 22.25 was considered for biogenic methane to account for the initial fixation of C. In this way, the part of the carbon cycle resulting in a neutral GHG balance (carbon fixation by plants and its rapid re-release due to e.g. respiration or combustion) was discounted from the impact assessment.

3 Results

3.1 Meta-product level

Figures 2, 3, 4, and 5 show the GHG emissions per tonne (squares and whiskers) and the contributions of each life cycle stage (pie charts) for dehydrated soups, wet soups, bouillon cubes, and liquid bouillons, respectively. The squares provide the median values of GHG emissions per tonne of finished product (as sold), while the whiskers show the 10th and 90th percentiles obtained from the Monte Carlo simulations. Note that the results per tonne of product as consumed would be significantly different for dehydrated and concentrated products, where most of the mass would be water added by the consumer. Thus, wet (ready-to-use) and dehydrated or concentrated products should not be compared based on the result shown below.

At a meta-product level, the relative contribution of each phase varies according to geography, consumer preference (flavour) and consumer-use patterns. Some general findings were:

- Invariably, the best opportunities for GHG emissions improvement (i.e. the biggest hotspots) lie upstream or

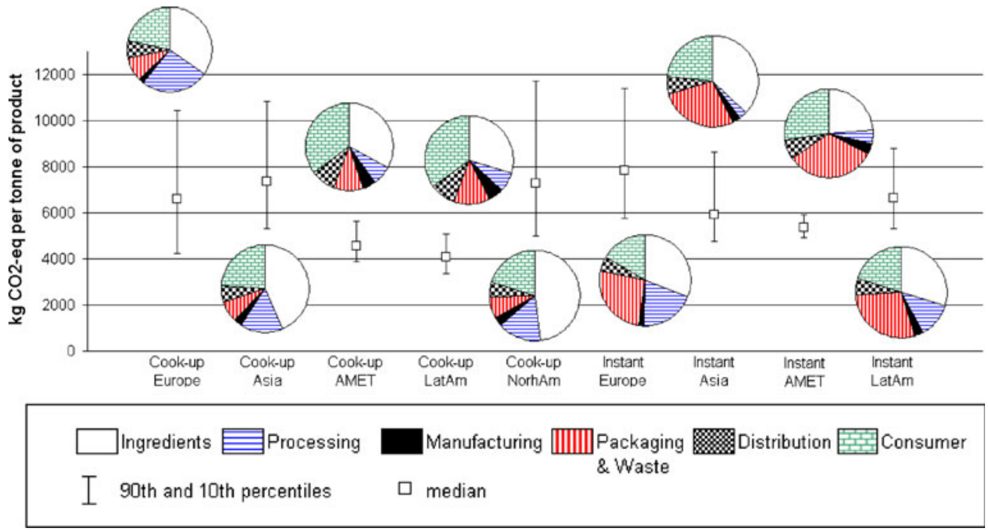

Fig. 2 GHG emissions in kilogram CO_2-eq per tonne of product (as sold) for the dehydrated soup meta-products assessed in the different regions

downstream from the Knorr factories (manufacture stage, black sector in Figs. 2, 3, 4, and 5), which only represent an average of 4% of the emissions. Exceptions to this are some of the wet products, where the contribution from the manufacture stage may be up to 17% and 35% (RTU aseptic soup and bouillon, respectively).

- In general, ingredients' production (white sector) and the use stage (horizontal bricks in Figs. 2, 3, 4, and 5) have the highest contributions to GHG emissions in most products.
- Ingredients' processing and packaging production also tend to have significant contributions to the total GHG emissions; these vary significantly across products.
- RTU products (wet soups and RTU liquid bouillons) show smaller contributions from the use phase, as this only requires heating up (as opposed to e.g. boiling water in dehydrated products).
- In bouillon cubes (see Fig. 4), product use (cooking) is by far the highest contributor to GHG emissions (usually >50%). It needs to be borne in mind that the worst-case scenario has been considered for these products, i.e. that all energy for boiling water is allocated to the bouillon, when the bouillon would actually be part of a more complex dish which could be allocated a large proportion of the impact.
- Product format is important: dry and concentrated products tend to have a lower GHG footprint per portion than similar wet products, even though their GHG footprint per kilogram is higher because they do not contain water in the recipe (this is only added by the consumer).
- Dry and concentrated products provide many more portions per kilogram than ready-to-use ones, as most of the mass is added by the consumer when re-hydrating them at home.
- The energy required to dehydrate ingredients for one portion of dry products is generally lower than that required to sterilise/pasteurise one portion of a ready-to-use wet product, which has a larger mass.
- Dry products require less packaging than wet products and are more efficient to transport.

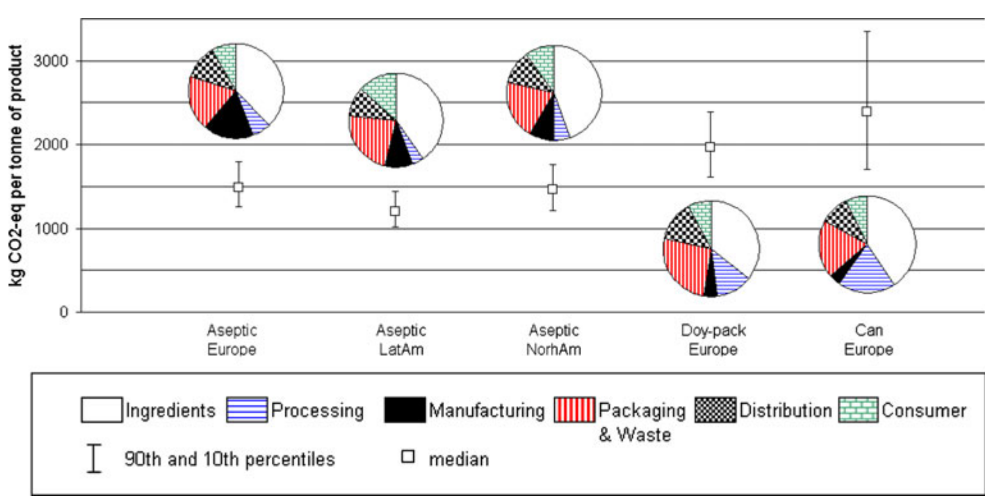

Fig. 3 GHG emissions in kilogram CO_2-eq per tonne of product (as sold) for the wet soup meta-products assessed in the different regions

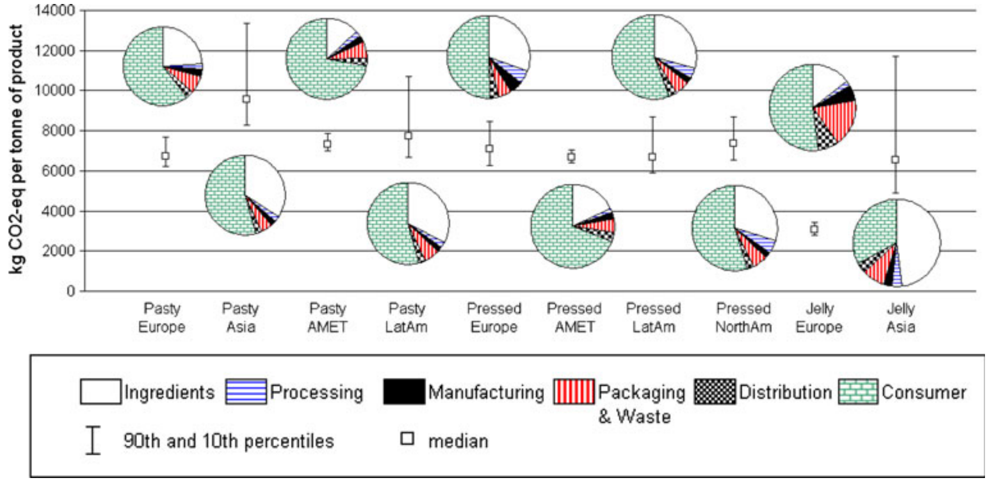

Fig. 4 GHG emissions in kilogram CO_2-eq per tonne of product (as sold) for the bouillon cube and bouillon jelly meta-products assessed in the different regions

- The packaging for instant dehydrated soups has a higher contribution than that for cook-up soups (see Fig. 2); this is due to the outer cardboard box present in instant soups (and not in cook-up ones).

From a variability point of view, the lognormal distribution assumed for the values of most parameters propagates into the "error bars" shown in Figs. 2, 3, 4, and 5, with fewer values between the median and the 10th percentile than between the median and the 90th percentile. The spread around the calculated medians varies substantially across meta-products, with some showing 80% of the values (10th–90th percentiles) within ±10% of the median and some meta-products spreading between −30% and +60%. Such variability in results is to be expected in bio-based products (see e.g. Williams et al. 2006; Milà i Canals et al. 2006; 2007; Lillywhite and Collier 2009). However, and in addition, the grouping performed with ingredients and some of the processing technologies explains part of the large variability considered for some of the 'building blocks', which in turn explains why variability is much larger for some meta-products (i.e. those using a large share of ingredients with large variability, and/or using ingredients with high GHG footprint). This second component of variability could be reduced if ingredient groups which contain too diverse elements were disaggregated.

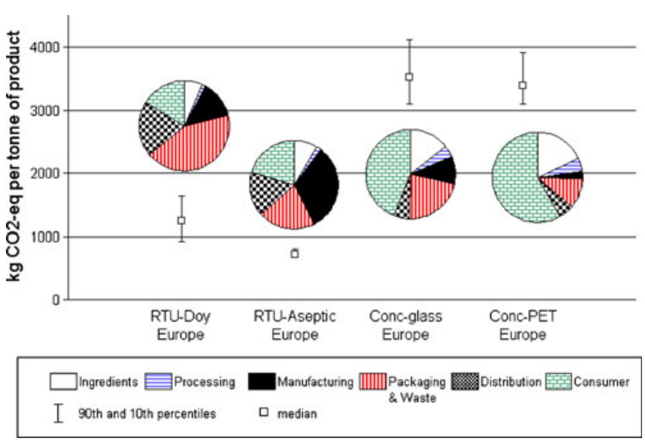

Fig. 5 GHG emissions in kilogram CO_2-eq per tonne of product (as sold) for the liquid bouillon meta-products assessed in the different regions

Considering variability reduces the discriminatory capacity between ingredients and eventually between meta-products (Lloyd and Ries 2007), but also enhances the robustness of the results: we are more certain that the impacts lie within the range suggested, even though we cannot always say whether meta-product A is better than B. In any case, inter-product comparison was not a goal of this study, and it would be misleading anyway given that the different meta-products provide different functions (e.g. many have different portion sizes, are eaten in different occasions…).

3.2 Brand level

The aggregated Knorr brand GHG footprint (GHGF) is shown in Fig. 6 and is estimated to be in the region of 3–5 million tonnes CO_2e/annum (95% confidence interval). This represents approximately 3% of the estimated Unilever GHGF, whereas the Knorr brand delivers approximately 7.5% of Unilever's turnover. At a brand level, the hotspots are ingredients' production (e.g. fertiliser and energy use to grow crops and animal products, energy use to produce flavours and other ingredients, etc.) and home cooking of Knorr products each representing one-third of the global GHGF. Primary processing of raw materials (e.g. energy use for activities such as drying, concentration of fruit and vegetables, and freezing) and the production of packaging materials each contribute about 10% to the total footprint; product manufacture in Knorr factories contributes about 4% to the total GHG emissions. Though ingredients for Knorr products are sourced from around the world, following the seasons to ensure quality and variety, transportation across the life cycle (including that of ingredients and final product distribution

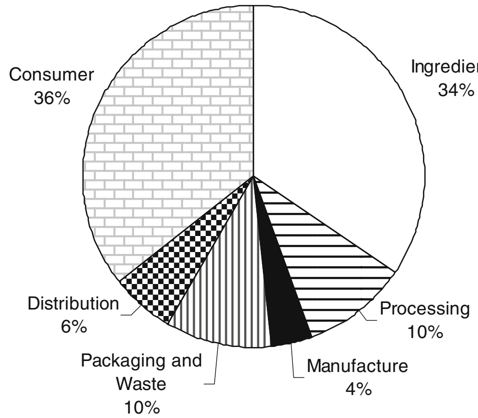

Fig. 6 Relative contribution to GHG emissions of the lifecycle stages for the total annualised sales of Knorr products globally

but excluding consumer purchase) accounts for 3% of the Knorr brand GHGF (shown within "Distribution" in Fig. 6, together with storage in warehouses).

4 Discussion

The study presented here is, to our knowledge, the world's first life cycle GHG assessment at brand product portfolio level, and shows how a simplification of the study system made feasible the assessment of a complex problem. The need to reduce modelling complexity in order to facilitate routine implementation of life cycle approaches in industry has been discussed e.g. by Bala et al. (2010), who also focus on GHG emissions. In addition to simplifying the model, lack of data availability has proven to be a major area requiring simplification; this has been overcome by resourcing to a variety of data sources and by grouping ingredients and processing technologies into a limited number of 'building blocks'. By assessing the variability around these generalised datasets, the certainty on the results is enhanced. However, what has been possible for a GHG assessment would be more difficult for other impact categories, for which data are less readily available.

It seems that the variability related to certain ingredient groups has a stronger effect on the overall product variability (e.g. two similar meta-products having clearly different variability ranges). Future iterations of this study should focus on refining those ingredient groups to see if the variability is natural or caused by grouping together ingredients which are clearly different (e.g. dairy products, meat products…).

The biggest opportunities for reducing GHG emissions lie upstream and downstream from the Knorr factories. Ingredients' growing and processing are one key area where engaging and influencing suppliers' practices may lead to significant GHG savings. Unilever has a long-standing history of working with farmers around the world to reduce their environmental impacts through the Sustainable Agriculture programme. Unilever's long-term aim is to buy its agricultural raw materials from sustainable sources; activities are being implemented to ensure the sustainability criteria include low-carbon farming practises. Opportunities in the use phase include working on products requiring less heating at home. Unilever continues to invest in reducing the GHG emissions from its own operations; for Knorr, this is particularly crucial for wet products, where sterilisation and pasteurisation processes generate a significant share of these products' overall GHG emissions. In this sense, work is underway to reduce heat requirements and increase the share of cleaner energy sources in Knorr factories.

5 Conclusions and recommendations

In conclusion, the main advantage of the 'meta-product' approach presented here is that it simultaneously allows for the overall assessment and comparison of individual product types as well as for the estimation of a brand's total GHGF. The former is important in terms of finding ways to reduce GHG emissions associated with existing products as well as driving innovation for lower carbon products; in this sense, Knorr is using the results of this study to inform brand strategy yielding less environmental impact. It can also provide a baseline against which the brand could set targets and track performance and form the basis for communication. However, recipes could vary significantly with respect to the weighted average recipe used for the meta-products; thus, recipe-specific results should be used to guide product innovation, as is currently being done by Knorr and other Unilever brands (Rigarlsford et al. 2010).

The variability assessment greatly supported the interpretation by identifying a confidence range around the GHG emissions for both product format (meta-product) assessment and comparisons and target setting. It confirmed that the results presented here are useful for strategic decisions, where orders of magnitude and directional trends suffice. The size of the variability range around the data also indicates that the current data quality in this exercise and for most agricultural ingredients is inappropriate to support single number on-pack carbon labels of products particularly given the complexity of many supply chains. Further work is needed to disaggregate the ingredient groups related to the largest variability. However, even if several ingredients were not grouped for practicality, their inherent variability would probably still make the final result too imprecise for labelling. Communicating GHG footprint results as a range rather than single points would be more credible and useful for strategic decisions and B2B communications, but possibly less understandable for the consumers.

It is also important to understand and differentiate between the factors that contribute to the variability and uncertainty. Firstly, those factors relating to uncertainty due to the applicability of the choice of data (e.g. technology, geography, and time relevance). Secondly, the variability associated with the technology or activity itself (e.g. agricultural yields, farming practises, different growers, etc., sometimes referred to as 'natural variability'). The variability assessment approach applied by ecoinvent based on DQI was found to be useful, but the factors tend to underestimate the measure of variability for many of the activities, particularly those relating to agriculture.

This study costs roughly the equivalent of 1 person-year, although several people worked on it over 2 years. An estimate of equivalent resource for a product-based study is difficult to calculate given the complexity of the portfolio to be assessed; it would however have been unlikely to be feasible given the time and resource constraints. In any case, the level of detail achieved with the project allowed to generate the required knowledge and to focus the attention for further research on e.g. product innovation. Moving forward, this type of approach is being used as part of Unilever's product innovation management process. The level of accuracy provided is enough, given the quality of data available, to inform product developers on the potential trends of innovations in terms of GHG emissions, putting them in an excellent position to manage such emissions. Such automation of the GHG assessment process has been made possible through the model simplification (Rigarlsford et al. 2010).

The study presented here focuses on one single environmental impact. A life cycle perspective is also important to address other sustainability issues either at an operational or strategic level, addressed with e.g. ingredient certification (sustainable sourcing). Even though consumer attention to GHG footprints is high, sustainable sourcing efforts are also high in the agenda. At a wider level, sustainability issues are only one of the aspects the consumer will look for, in addition to nutrition, taste, perceived quality, convenience, price, etc.

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